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PATENT SPECIFICATION



DRAWINGS ATTACHED

890,089

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COMPLETE SPECIFICATION

Improvements in Hydropneumatic Vehicle Suspensions

5 We, AKTIEBOLAGET VOLVO, a Swedish Body
Corporate, of Hisingen, Gothenburg H,
Sweden, do hereby declare the invention, for
which we pray that a patent may be granted
to us, and the method by which it is to be per-
formed, to be particularly described in and by
the following statement:—

This invention relates to hydropneumatic vehicle suspension.

10 Hydropneumatic vehicle suspension devices are known in which a telescopic piston-cylinder element serves both as a springing device and a damping device. The object of the invention is to improve the construction of the telescopic elements such that the telescopic elements in addition to fulfilling the above-named functions can serve as anti-roll and anti-pitch members. The telescopic elements are pivotally inserted between the sprung and unsprung parts of the vehicle and consist each of a differential area piston movable in a cylinder having differential spaces of different sizes filled with a pressure liquid, and there are further provided pressure containers having each a space for pressure liquid and a space for a compressed gas separated from each other by an elastic diaphragm. The invention is characterized by the fact that the differential spaces in each telescopic element are separated from each other and that the larger differential space in a telescopic element on one side of the vehicle communicates with the smaller differential space in the telescopic element on the other side of the vehicle and with the liquid space in a first pressure container, whereas the smaller differential space in the telescopic element on the first-named side of the vehicle communicates with the larger differential space in the telescopic element on the other side of the vehicle and with the liquid space in a second pressure container. Due to this cross-connection of the differential spaces of the telescopic elements on both sides of the vehicle there is obtained the advantage that the springing action is stiffer in case of a rolling motion than in case of a

parallel motion of the sprung part of the vehicle such that the device acts both as a springing device and an anti-roll device. If the telescopic elements on one and the same axle are cross-connected to each other, there is only obtained an anti-roll action. If, however, the telescopic element on one side and on one axle is cross-connected with the telescopic element on the other side and on another axle, there is obtained an anti-roll action as well as an anti-pitch action. The advantage obtained by the invention consists in that special mechanical anti-roll and anti-pitch members are not necessary and that the resistance of the vehicle to roll and pitching will not vary as much with varying load as in case of mechanical anti-roll and anti-pitch members. If mechanical anti-roll and anti-pitch members are used, their dimensions must be such as to provide for a satisfactory resistance to roll and pitching when the vehicle is fully laden. In an unladen vehicle the rolling and pitching forces are lower due to the lower weight of the vehicle and due to the fact that the center of gravity of the vehicle lies at a lower level. In this case, mechanical anti-roll and anti-pitch members will be too strong when the vehicle is partly laden or unladen, the result being harsh and unsatisfactory riding characteristics of the vehicle.

If, in contrast thereto, hydropneumatic 75
anti-roll and anti-pitch action is used, the
resistance to roll will vary in accordance with
the load, since the hydropneumatic springs are
combined, in a manner known per se, with
levelling devices which at varying load auto- 80
matically maintain constant the ground clear-
ance by supplying pressure liquid to, or with-
drawing it from, the liquid spaces of the
springs. With decreasing load, the gas will
expand in the pressure containers. The in- 85
creasing gas volume in the pressure containers
upon decreasing load results in a softer action
of the springs as well as the anti-roll and anti-
pitch actions so that in many cases the rolling
and pitching movement of the vehicle will be 90

practically constant.

The construction of the telescopic elements with separate differential spaces in accordance with the invention can also be used as a simple 5 and effective wheel lift. To this end, the telescopic elements are combined with a structure characterized by a shut-off valve provided in the connecting conduit between the large differential space of the telescopic 10 element and the communicating liquid space of the pressure container, and further comprising a conduit between the large differential space and the low-pressure side of the pressure liquid system, the last-named conduit also 15 being provided with a shut-off valve. If the valve between the large differential space and the pressure container is closed and the valve for the low-pressure conduit is opened, the wheel will be lifted by the pressure in the 20 small differential space. This construction facilitates tire changing especially in heavy vehicles, and in vehicles provided with tandem axles it may serve to lift one pair of wheels at 25 low loads. Moreover, the shut-off device may be used to lock the wheels in a certain position which may be desirable, for instance, during loading and unloading or if a crane with a swinging boom is mounted on the vehicle.

From the above it follows that the telescopic 30 elements according to the invention serve the functions of springs, shock absorbers, anti-roll members, anti-pitch members and wheel lifts.

Further objects and advantages of the invention will appear from the following description with reference to the annexed drawing.

Fig. 1 shows diagrammatically and partly in section an axle of a vehicle with independent wheel suspension and a spring device according 40 to the invention. Figs. 2, 3, 4 and 5 are diagrammatical illustrations of the mode of operation of the spring device in case of parallel springing movement, rolling movement and one-sided springing movement. Figs. 6 and 7 are diagrammatic illustrations of an embodiment of the invention adapted to act as springs, shock absorbers, anti-roll members and anti-pitch members. Fig. 8 is a diagrammatic view of a device according to the invention as applied 50 to tandem axles, Fig. 9 a sectional view and Fig. 10 a lateral view of a telescopic element according to the invention, and Fig. 11 a sectional view of part of a telescopic element according to a modified construction.

Referring to Fig. 1, the wheels 1 of the front axle of a vehicle are by means of suspension arms 2 and 3 pivotally connected with the frame or sprung part 4 of the vehicle. Pivotally inserted between the suspension arms 3 and 60 the frame 4 are telescopic elements, the left-hand element consisting of a differential cylinder 5 and a differential area piston 6, and the right-hand telescopic element consisting of a differential cylinder 7 and a differential area piston 8. The differential piston 6 divides

the differential cylinder 5 into two separate chambers, namely, a larger differential space 9 and a smaller differential space 10. In a similar manner, the right-hand telescopic element has a larger differential space 11 and a 70 smaller differential space 12. The differential space 9 in the left-hand telescopic element communicates through a duct 13 in the differential piston 6 and a flexible conduit 14 with the differential space 12 of the right-hand 75 telescopic element. The conduit 14 also communicates with the liquid space 15 in a pressure container 16. An elastic diaphragm 17 separates the liquid space 15 from a gas space 18 in the pressure container 16. In a similar manner, the differential space 10 in the left-hand telescopic element communicates through a conduit 20 and a duct 21 with the differential space 11 in the right-hand telescopic element and with the liquid space 22 in a pressure 80 container 23. An elastic diaphragm 24 divides this container into a liquid space 22 and a gas space 25. Levelling devices 26 actuated by the suspension arms 3 connect the conduits 14 and 20, respectively, either with a conduit 27 for a high-pressure liquid or with a low-pressure or return conduit 28. In the conduit 14 between the differential space 9 and the liquid space 15 in the container 16 there are provided a shut-off valve 29 and a damping device 30. 95 Similarly, a shut-off valve 31 and a damping device 32 are provided in the conduit 20 between the differential space 11 and the liquid space 22. By means of connecting conduits 33 and 34 provided with shut-off valves 35 and 36, respectively, the larger differential space 9 or 11 can be connected with the return conduit 28. 100

The mode of operation of the device according to the invention is best described with reference to Figs. 2, 3, 4 and 5 in which similar parts are denoted by the same reference numerals as in Fig. 1. In these Figures the telescopic elements are placed upside down as compared with Fig. 1. Also, the cylinders 5 and 7 are connected with the sprung part of the vehicle, and the connecting conduits 14 and 20 between the differential spaces 9, 12 and 10, 11, respectively, are directly connected to the cylinders 5 and 7, respectively. 115

In Figs. 1 and 2, the telescopic elements are shown in their intermediate positions. The levelling devices shown in Fig. 1 always tend to return the springs to this position. If a telescopic element is contracted, for instance due to an increased load on the vehicle, the levelling device 26 permits flow of pressure liquid from the high-pressure conduit 27 to the liquid space 15 in the pressure container 16 until the telescopic element has regained its original length. At decreasing load the levelling device 26 permits pressure liquid to pass from the liquid space 15 to the return conduit 28 until the vehicle clearance height has reassumed its normal value. Preferably, the levelling 120 125 130

device 26 is provided, in a manner known per se, with a restriction or delaying device which prevents changing of the clearance height under the influence of the normal spring 5 movements.

Assuming now that the vehicle strikes a symmetric elevation of the ground so that both wheels are simultaneously forced upwards, the telescopic elements will be contracted from 10 the intermediate positions shown in Figs. 1 and 2 to the positions shown in Fig. 3. As will be seen from the drawing, the volume of the differential space 9 in the left-hand telescopic element will be reduced thereby and simultaneously 15 the volume of the communicating differential space 12 in the right-hand telescopic element will be increased. The difference between these changes in volume, or the positively displaced amount of liquid, will flow to 20 the pressure container 16 and will compress the gas enclosed in the space 18. The volume of the liquid actually displaced from the differential spaces 9 and 12 obviously equals the volume which a piston having the smaller 25 diameter of the differential piston 6 would displace for the same piston stroke. It can be said, therefore, that the spring rate for a symmetric springing movement will be the same as in the case where a piston having the smaller 30 diameter of the differential piston would work against the gas volume 18 enclosed in the pressure container 16. Exactly the same consideration holds true of the right-hand telescopic element and the right-hand pressure 35 container 23.

Assuming now instead a rolling action of the vehicle, the left-hand telescopic element will be expanded and the right-hand telescopic element will be contracted, as exemplified in 40 Fig. 4. In this case the volume increases both in the differential space 9 of the left-hand telescopic element and the communicating differential space 12 of the right-hand telescopic element, the result being a large reduction of 45 the volume of the liquid space 15 in the pressure container 16 and a corresponding large expansion of the gas in the space 18. At the same time, the volume is reduced both of the differential space 10 in the left-hand telescopic 50 element and the communicating differential space 11 in the right-hand telescopic element, resulting in a high displacement of liquid into the liquid space 22 of the pressure container 23 and a corresponding high compression of the 55 gas in the space 25. Consequently, a rolling action will result in larger pressure variations than a parallel movement, and said pressure variations act on a larger piston area, namely, on the sum of both pressure areas of the differential piston. Speaking exactly, a rolling 60 action results in a pressure variation which is determined by the sum of the liquid volumes displaced by both piston surfaces of the differential piston, and the resulting pressure variation acts on the sum of both piston areas

of the differential piston. On the other hand, a parallel springing movement causes a pressure variation determined by the difference of the liquid volumes displaced by both piston areas of the differential piston, and the resulting 70 pressure variation acts only on the difference between the two pressure areas of the differential piston. Consequently, a rolling action results in a stiffer springing action than a parallel springing movement. The difference 75 between the spring rates is determined by the diameter ratio of the differential piston. The greater this diameter ratio the higher is the resistance to roll of the vehicle as compared with the rigidity of the springs during symmetric springing movements. By way of example, for a diameter ratio of 1 : 1.25 the spring rate in case of a rolling action is 4.5 times the spring rate in case of symmetric 80 springing movement.

Fig. 5 explains the mode of operation in case of a one-sided springing movement. It may be assumed that the left-hand telescopic element remains unmoved in its intermediate position, whereas the right-hand telescopic 90 element is subjected to a contraction. In this case liquid will be displaced from the differential space 11 of the right-hand telescopic element, resulting in a certain compression in the gas space 25 of the pressure container 23. At the same time, the volume of the differential space 12 in the right-hand telescopic element is increased, resulting in a certain expansion in the gas space 18 of the pressure container 16. In the present case, the pressure variations 95 are smaller than in case of rolling movement because of the fact that the volumetric changes are induced in one telescopic element only.

The final outcome is that the value of the spring rate for one-sided springing movement 105 lies somewhere between the values for symmetric springing movement and rolling action. Summing up, it can be said that the springing device according to the invention renders 110 possible the construction of a vehicle with high resistance to roll and nevertheless soft springing action in case of symmetric and one-sided wheel movements.

Figs. 6 and 7 illustrate how a single hydro-pneumatic suspension member for each wheel in accordance with the invention can combine the actions of anti-roll and anti-pitch members. In both of these Figures the two upper suspension devices may be assumed to be associated with the front axle of a vehicle and the lower suspension devices with the rear axle of the vehicle. As described above with reference to Fig. 1, each suspension device comprises a cylinder 5, a differential area piston 6, a damping device 30, a pressure container 16 and a levelling device 26. In the embodiment according to Fig. 6, the differential space 9 in the left-hand telescopic element of the front axle communicates with the differential space 37 in the right-hand telescopic element of the 120 125 130

rear axle, whereas the differential space 10 in the left-hand telescopic element of the front axle communicates with the differential space 11 in the right-hand telescopic element of the 5 front axle. The differential space 38 in the left-hand telescopic element of the rear axle communicates with the differential space 12 in the right-hand telescopic element of the front axle, and the differential space 39 in the left- 10 hand telescopic element of the rear axle communicates with the differential space 40 in the right-hand telescopic element of the rear axle.

The mode of operation of the device illustrated in Fig. 6 is as follows. In case of a 15 parallel springing movement of all four wheels the operation is obviously the same as in case of a symmetric movement of the two wheels in the embodiment according to Fig. 1. Also in case of rolling movement of the entire vehicle 20 according to Fig. 6 the same resistance to roll is obtained as in the case of roll of a single axle according to Fig. 1. Finally, it will be apparent that for a springing movement of a single wheel the mode of operation will be the 25 same in both cases. Now let us assume a pitching movement of the sprung part of the vehicle, for instance a compression of the front springs and an extension of the rear springs as a result of braking, the volume will 30 be reduced simultaneously in the communicating spaces 9 and 37 and will be increased simultaneously in the communicating spaces 12 and 38. In the communicating spaces 11 and 10 the volume will be decreased and increased, respectively, and there will also be a 35 decrease and increase of the volumes of the communicating spaces 39 and 40, respectively. Consequently, half the number of the inter- 40 communicating spaces will act to resist roll and half the number will act to resist parallel springing movement in the manner previously described.

Therefrom it follows that the resistance of 45 the springing device to pitching movement lies between the resistance to roll and the resistance to parallel springing movement, which is often a suitable relation of the various spring rates, since in most vehicles the wheel base is longer than the track, for which reason a resistance 50 to pitching smaller than the resistance to roll will be satisfactory.

In the embodiment illustrated in Fig. 7 the telescopic elements of the front axle are completely cross-connected with the telescopic 55 elements of the rear axle. This arrangement need not be described in detail as it is obvious for reasons of symmetry that the spring resistance to roll will be the same as the resistance to pitch. Consequently, this arrangement may 60 be suitable in vehicles have a relatively short wheel base.

Summing up, it can be said that the spring devices according to Figs. 6 and 7 render 65 possible the construction of a vehicle having a relatively high resistance to roll and pitch and

a soft springing action for parallel springing movement. A soft springing action can also be obtained for individual wheels, individual axles or for the springing movement of the wheels on one side of the vehicle. In other 70 words, a stable vehicle can be obtained which nevertheless has soft springing movements.

Fig. 8 shows an embodiment of the invention as applied to tandem or so-called bogie structures. The upper telescopic elements having 75 the larger differential spaces 41 and 42 and the smaller differential spaces 43 and 44 are connected to one axle of the bogie, whereas the lower telescopic elements having the larger differential spaces 45 and 46 and the smaller 80 differential spaces 47 and 48 are connected to the other axle of the bogie. The large differential spaces 41 and 45 of the left-hand telescopic elements communicate with each other and with the smaller differential spaces 44 and 48 85 of the right-hand telescopic elements and with the liquid space 49 in the pressure container 50. Similarly, the smaller differential spaces 43 and 47 of the left-hand telescopic elements communicate with each other and with the large differential spaces 42 and 46 of the right- 90 hand telescopic elements and with the liquid space 51 in the pressure container 52. In the same manner as previously described, shut-off valves 29 and damping members 30 are provided in the conduits connected to the large differential spaces 41, 42, 45 and 46, and each of said spaces is connected to a return conduit 33 having a shut-off valve 35. Only two levelling devices 26 are provided for the four wheels 100 of the bogie, and these levelling devices are preferably adapted to be acted upon by the 105 wheels of one and the same axle.

The mode of operation of this arrangement is as follows. Since both of the large differential spaces 41 and 45 on one side of the vehicle and the small differential spaces 43 and 47 on the same side are arranged in parallel relation to each other, the load is always uniformly distributed between the wheels on one side of the vehicle. Further, the arrangement according to Fig. 8 offers the advantage that the springing action will be twice as soft if the wheels of one axle only strike an obstacle. Finally, the gas 110 volume and the pressure in the springs will not be affected if the wheels of one axle strike an obstacle and the wheels of the other axle simultaneously go down into an equally deep hole. These advantages, that is, equally distributed load and softer springing action, are 115 the same as are obtained in conventional bogie structures having mechanical balance arms between the wheels on one side. Consequently, it can be said that the structure according to Fig. 8 functions as a hydraulic balance arm 120 wherein a few relative light and inexpensive conduits replace the relatively heavy and expensive mechanical balance arms and their joints. The arrangement according to the 125 invention further offers the advantage that the 130

axle structure itself is the same for single axles and bogies, whereas bogies with mechanical balance arms require special constructions.

- 5 In other respects, the arrangement according to Fig. 8 operates in the same manner as described with reference to Fig. 1, and the same differences of the spring rates are obtained in case of parallel springing movement, one-sided springing movement and rolling movement. Further, it will be obvious that by combining the arrangement according to Fig. 8 with the arrangement according to Fig. 6 or 7 there can be obtained the action of an anti-pitch member for vehicles with two bogies or with a bogie and a single axle.

Figs. 9 and 10 illustrate a more specific construction of a telescopic element.

The cylinder comprises a cylindrical tube 53, 20 a bushing 54 and a bottom plate 55 bolted to a yoke 56 which by means of two journals 57 is pivotally mounted in the suspension arm 3. Movable in the cylinder is a differential area piston consisting of a piston member 58 and 25 a piston tube 59. The top end of the piston tube 59 is secured to a head 60 which by means of two journals 61 is pivotally mounted in the chassis or sprung part 62 of the vehicle. Provided between the cylinder and the differential 30 piston are the larger differential space 9 and the smaller differential space 10 which are sealed against each other by means of a sealing member 63 provided in the piston 58. The interior of the piston tube is by means of a 35 tube 64 divided into an outer piston space 65 and an inner piston space 66. The smaller differential space 10 of the telescopic element communicates through openings 67 with the outer piston space 65 and through a bore in 40 the left-hand journal 61 and a hose connection 68 and the flexible conduit 20 shown in Fig. 1 with the pressure container 23. The large differential space 9 of the telescopic element communicates with the inner piston space 66 45 and through a bore in the right-hand journal 61 and a hose connection 69 and the flexible conduit 14 shown in Fig. 1 with the pressure container 16. A dust cover 70 protects the sliding surface of the piston tube 59 and the 50 sealing member in the bushing 54 against dust and splash. Pressed into the bottom plate 55 is a tube 71 having bores 72, a non-return valve 73 and apertures 74.

The mode of operation of the telescopic element according to Figs. 9 and 10 will be apparent from the previous parts of the description. At a springing movement of the wheel 1 shown in Fig. 1 the suspension arm 3 will swing between the central lines 75 shown 60 in Fig. 10, resulting in a shorter swinging movement of the telescopic element between the central lines 76, this swinging movement being possible due to the movability of the journals 61 and the flexibility of the conduits 65 14 and 20. Fig. 11 shows a modification of the

pivotal mounting of the differential piston 58, 59 in the chassis or sprung part 4 of the vehicle and the connection between the differential piston and the conduits 14 and 20. Two brackets 77 bolted to the chassis 4 serve 70 as supports for the bearings for the two journals 61 and also as turnable bushings provided with packings 78. The journals 61 and the bushings in the brackets 77 are in coaxial alignment so as to permit the telescopic element to perform its angular movement between the central lines 76 shown in Fig. 10. With this arrangement, the connecting conduits 14 and 20 may be fixed tubes in the chassis 4.

The tube 71 in the cylinder serves as a 80 buffer for limiting the compression stroke of the telescopic element. To this end, the tube 71 is dimensioned such that it will practically shut off the large differential space as it enters the inner tube 64 of the differential piston. As 85 a result thereof, the liquid contained in the large differential space 9 will be forced through the holes 72 into the tube 71. The desired stroke limiting buffer action can be obtained by suitable location and dimensioning of the holes. During this part of the operation the non-return valve 73 is maintained in closed 90 position. Immediately at the beginning of the expansion stroke the non-return valve 73 opens so as not to prevent the normal function of the telescopic element as a spring. In a similar manner, the holes 67 in the piston tube 59 act as stroke limiting buffers during the expansion stroke of the telescopic element. In this case, the stroke limiting buffer action takes place 100 as the bushing 54 more and more covers the holes 67, thereby causing a pressure rise in the smaller differential space 10.

WHAT WE CLAIM IS:—

1. A hydropneumatic vehicle suspension 105 comprising telescopic elements pivotally inserted between the sprung and unsprung parts of the vehicle and consisting each of a differential area piston movable in a cylinder having differential spaces of different sizes filled with 110 a pressure liquid, and further comprising pressure containers having each a space for pressure liquid and a space for a compressed gas separated from each other by an elastic diaphragm, characterized in that the differential spaces in 115 each telescopic element are separated from each other and that the larger differential space in a telescopic element on one side of the vehicle communicates with the smaller differential space in the telescopic element on the other side of the vehicle and with the liquid space in a first pressure container, whereas the smaller differential space in the telescopic element on the first-named side of the vehicle communicates with the larger differential space in the 120 telescopic element on the other side of the vehicle and with the liquid space in a second pressure container.
2. A hydropneumatic vehicle suspension 125 according to claim 1, characterized in that the 130

- telescopic elements are provided on one and the same axle of the vehicle.
3. A hydropneumatic vehicle suspension according to claim 1, characterized in that the telescopic elements are provided on different axles of the vehicle.
4. A hydropneumatic vehicle suspension according to claim 3, characterized in that each smaller differential space in the telescopic elements on one side of the vehicle communicates with the larger differential space in the telescopic elements on the same axle and on the other side of the vehicle and with the liquid space in different pressure containers,
- 10 13 and that each larger differential space in the telescopic elements on the first-named side of the vehicle communicates with the smaller differential space in the telescopic elements on another axle and on the other side of the vehicle and with the liquid space in different pressure containers (Fig. 6).
- 14 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
5. A hydropneumatic suspension according to any of claims 1 to 4 for vehicles having double wheel axles or tandem axles, characterized in that the larger differential spaces in the telescopic elements provided on one side and associated with the same pair of axles communicate with each other and with the liquid space in a common pressure container,
- 30 and that the smaller differential spaces in the telescopic elements provided on the same side and associated with the same pair of axles communicate with each other and with the liquid space in another common pressure container.
6. A hydropneumatic suspension according to any of the preceding claims, characterized by a levelling device responsive to variations of the distance between the sprung part and the unsprung part of the vehicle such as to permit supply of liquid under pressure to the larger differential space of the appertaining telescopic element when said distance is smaller than normal and to permit withdrawal of liquid under pressure from said differential space when said distance is longer than normal.
7. A hydropneumatic suspension according to any of the preceding claims, characterized by damping devices provided in the connecting conduits between the differential spaces of the telescopic elements and the liquid spaces in the pressure containers.
8. A hydropneumatic suspension according to any of claims 1 to 6, characterized in that a damping device is provided in the connecting conduit between the large differential space of each telescopic element and the communicating liquid space of the pressure container.
9. A hydropneumatic suspension according to any of the preceding claims, characterized by a shut-off valve provided in the connecting conduit between the large differential space of the telescopic element and the communicating liquid space of the pressure container and by a conduit including a shut-off valve and provided between the larger differential space and the low-pressure side of the pressure liquid system.
10. A hydropneumatic suspension according to any of the preceding claims, characterized in that the differential cylinder is pivotally connected with the unsprung part of the vehicle and that the differential piston is pivotally connected with the sprung part of the vehicle.
11. A hydropneumatic suspension according to claim 10, characterized in that the differential piston consists of an annular piston connected with two concentric tubes which define an inner and an outer piston space, the inner space communicating with the larger differential space, and the outer space communicating with the smaller differential space.
12. A hydropneumatic suspension according to claim 11, characterized in that the upper end of the differential piston is provided with two hollow journals arranged symmetrically with respect to the axis of the differential piston and coaxially with respect to an axis at right angles to the axis of the differential piston, the interior of one journal communicating with the inner space of the differential piston, and the interior of the other journal communicating with the outer space of the differential piston.
13. A hydropneumatic suspension according to any of the preceding claims, characterized by a yoke secured to the bottom of the differential cylinder, both ends of the yoke forming journals having a common axis located at right angles to the axis of the telescopic element.
14. A hydropneumatic vehicle suspension, damping and stabilizing device, substantially as described with reference to any of Figs. 1 to 11 of the accompanying drawing.

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Sheet 1

Fig. 1

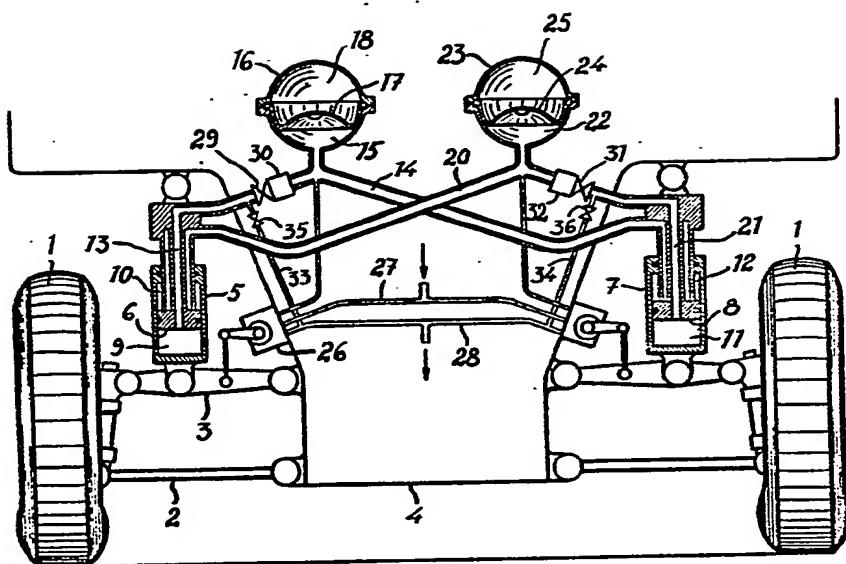


Fig. 2

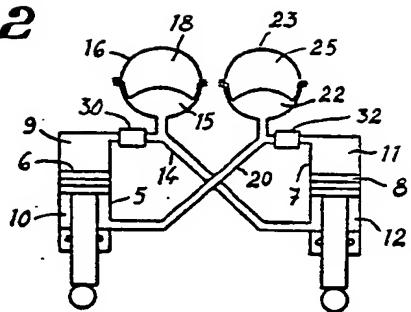


Fig. 4

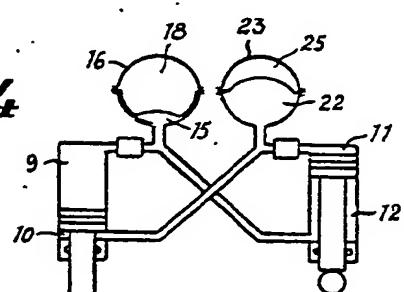
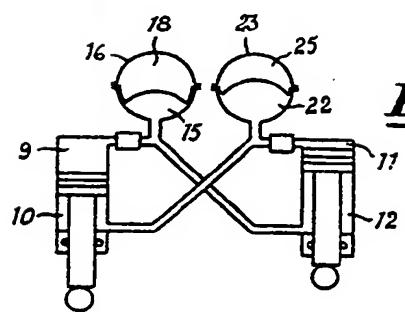


Fig. 5



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FIG. 6

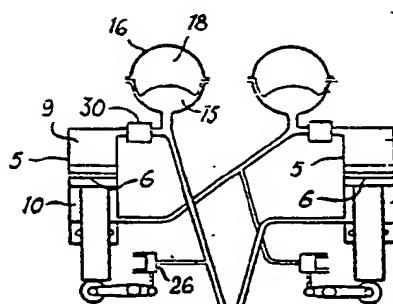
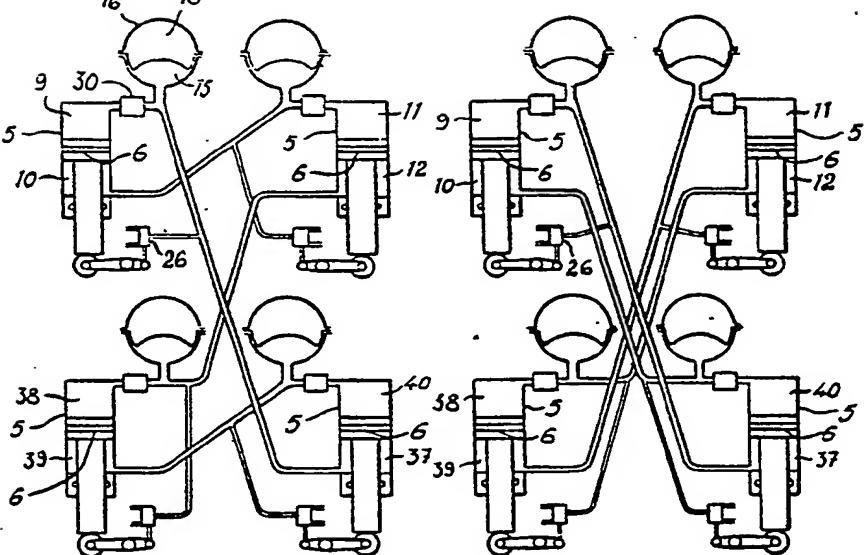


FIG. 7



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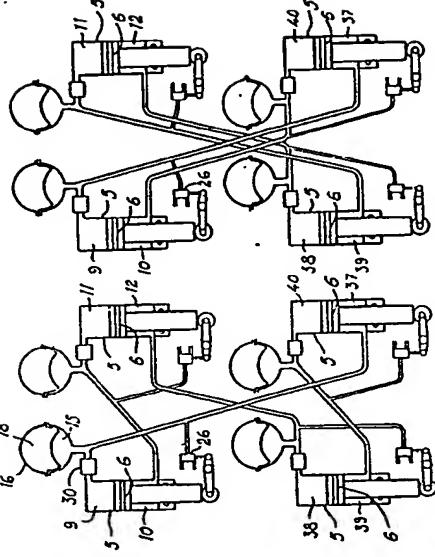
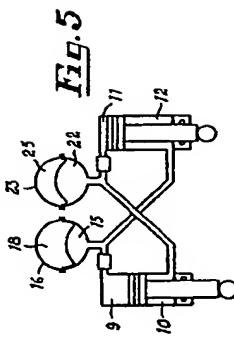
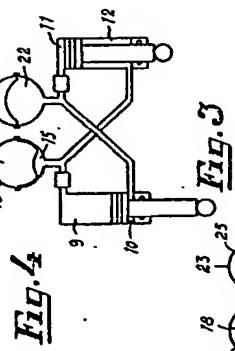
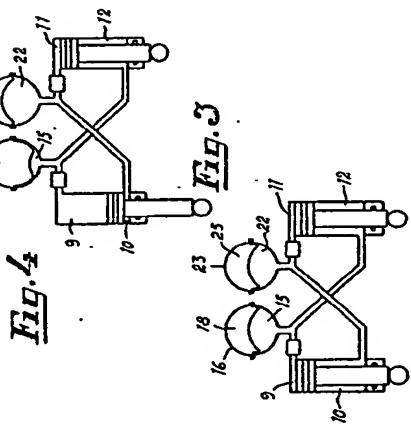
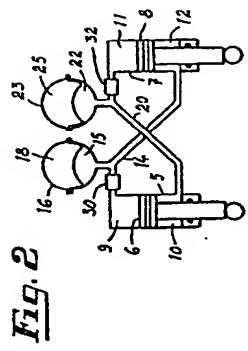


Fig. 8

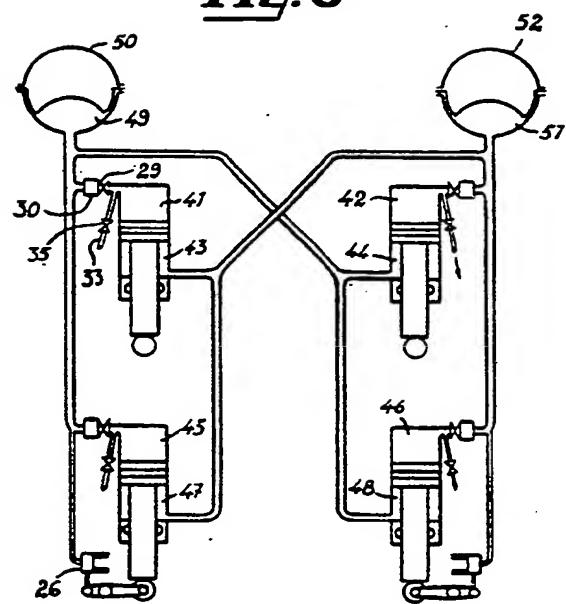
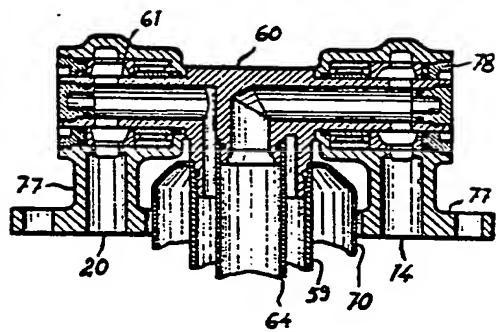


Fig. 11



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the Original on a reduced scale*

Sheets: 4 & 5

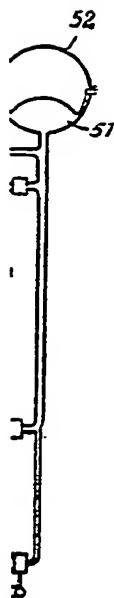


Fig. 9

